

Measurement of charged-particle production in single diffractive proton-proton collisions with the STAR detector.

Leszek Adamczyk* for the STAR Collaboration

Faculty of Physics and Applied Computer Science, AGH University of Science and Technology,
30 Mickiewicza Ave., b30-059 Kraków, Poland

* leszek.adamczyk@agh.edu.pl

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Abstract

We present results on the inclusive and identified (pion, kaon, proton and their antiparticles) charged-particle production in single diffractive (SD) dissociation process in proton-proton collisions at $\sqrt{s} = 200$ GeV with the STAR detector at RHIC. The forward-scattered proton is measured in the Roman Pot (RP) system, while the charged particle tracks are reconstructed in the STAR Time Projection Chamber. The proton-antiproton production asymmetry is measured to study the baryon number transfer over a large rapidity interval in SD process. In addition, K/π ratio is measured, showing a larger strangeness production at $p_T > 0.5$ GeV/c compared to measurements in inclusive proton-proton collisions.

1 Introduction

The yields of charged-hadrons emitted in high-energy particle collisions are among basic observables used to study Quantum Chromodynamics in both perturbative and non-perturbative regimes. The most significant contribution to the number of produced particles comes from soft interactions, which are usually modeled phenomenologically. In this paper we present studies for a class of pp collisions, $p + p \rightarrow p + X$, where X denotes the hadronic final state produced in the interaction due to dissociation of the beam proton, in which other of the colliding protons escapes the collision intact at a very small angle and is measured in the Roman Pot (RP) system. Experimentally diffractive events are often defined as the events with large rapidity gaps, which are not exponentially suppressed. However experiments equipped with tracking detectors in RP for detecting forward scattered protons use a more strict definition in terms of a leading proton taking a large fraction of the beam proton momentum. We also study anti-proton to proton multiplicity ratio as a function of the particle transverse momentum, p_T and the relative energy loss of the forward-scattered proton, ξ . This study aims toward a better understanding of the baryon number transfer in single diffractive (SD) process. Since most of the baryons are created as baryon-anti-baryon pairs in the hadronization process, it is expected that the same amounts of baryons and anti-baryons should be observed in the central rapidity region, and the initial baryon number should appear in the very forward direction. In addition we measure kaon to pion multiplicity ratio. Such ratio is sensitive to the strangeness production in the fragmentation process. Strangeness production in inclusive pp collisions was observed to be significantly suppressed compared to up and $down$ quarks production [1].

2 Results

The STAR experiment [2] at RHIC has performed a high-statistics measurement of the SD process in pp collisions based on a sample collected in 2015 at the center-of-mass energy $\sqrt{s} = 200$ GeV corresponding to an integrated luminosity of 15 nb^{-1} . The comparison to the corrected data distribution is done for several Monte Carlo (MC) generators: the 4C tune of PYTHIA 8 [3] with SaS (Schuler and Sjöstrand) [4] model, version 7.1 of the HERWIG generator [5] which includes a new model for soft interactions and diffraction [6], the EPOS [7] tuned to LHC data (EPOS-LHC) [8]. In addition all results are compared to the alternative A2 tune [9] of PYTHIA 8, with the MBR (Minimum Bias Rockefeller) model [10] and to MBR expectation without arbitrary suppression of the cross section at relatively large values of ξ (MBR-tuned). EPOS predicts a very large contribution of the forward protons well separated in rapidity from other final state particles from non-diffractive events. Therefore, for the comparison with data EPOS-LHC predictions are separated into two classes: EPOS-LHC SD, with diffractive flag, and EPOS-LHC SD', with non-diffractive flag. For the purpose of this measurement, EPOS SD' sample is selected by requirement that the mass of the excited beam remnant is low (< 1 GeV), and only proton is produced from it while EPOS ND consists of other non-diffractive events.

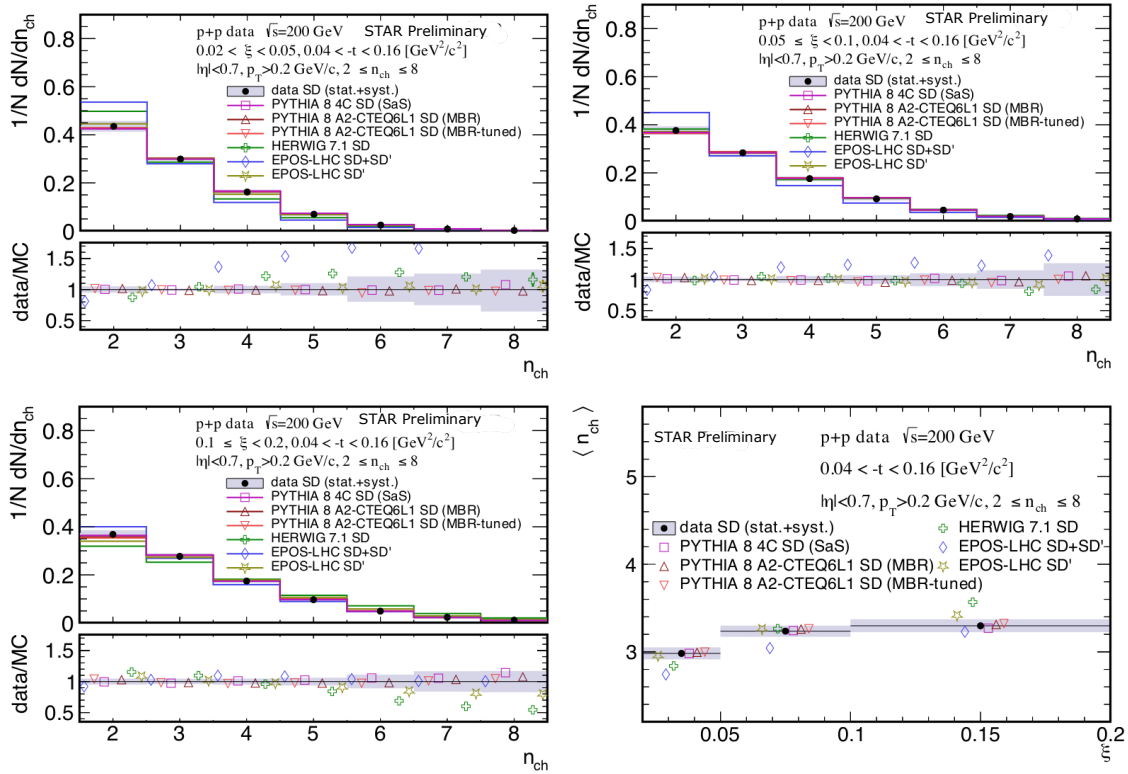


Figure 1: Primary charged-particle multiplicities shown in three ranges of the ξ : (top left) $0.02 < \xi < 0.05$, (top right) $0.05 < \xi < 0.1$, (bottom left) $0.1 < \xi < 0.2$. (bottom right) The mean multiplicity $\langle n_{\text{ch}} \rangle$ as a function of ξ . Data are shown as full dots with error bars representing the statistical uncertainties. Gray boxes represent statistical and systematic uncertainties added in quadrature. Predictions from MC models are shown as histograms or the open symbols. The bottom panels show ratios of data to the MC models predictions. In the ratio plots and in the $\langle n_{\text{ch}} \rangle$ distribution, points representing different MC models are spread within bins for better visibility.

In Fig. 1 we show multiplicity distributions of charged particles in different intervals of

50 ξ as well as the average values of n_{ch} in those ξ ranges. Data exhibit an expected increase
 51 of the $\langle n_{\text{ch}} \rangle$ with ξ due to the larger diffractive masses probed at increasing ξ in SD process.
 52 The shapes of the measured distributions are reproduced reasonably well by all models except
 53 the EPOS-LHC (SD+SD'), which predicts much smaller $\langle n_{\text{ch}} \rangle$ at $\xi < 0.1$ and the HERWIG SD,
 54 which for $0.1 < \xi < 0.2$ predicts too large $\langle n_{\text{ch}} \rangle$. It should be noted, that EPOS-LHC SD'
 55 describes data much better compared to EPOS-LHC (SD+SD').

56 We compare present measurement of charged particle density with non single diffractive
 57 enhanced (NSD) measurements. For this comparison present results were extrapolated from
 58 the fiducial $|\eta| < 0.7$ region to midrapidity region $\eta_m = -\ln(\sqrt{s}/M_X)$. Extrapolation was per-
 59 formed based on model implemented in PYTHIA 8 and includes also correction for $n_{\text{ch}} = 1$
 60 events not included in present measurement. Figure 2 shows densities of charged-particles at
 61 midrapidity as a function of \sqrt{s} and M_X for NSD enhanced measurements and present results,
 62 respectively. SD points lay very well on the power-like fit to the NSD enhanced measure-
 63 ments [11] showing similarity of charged particle densities at midrapidity between SD and
 NSD enhanced measurements.

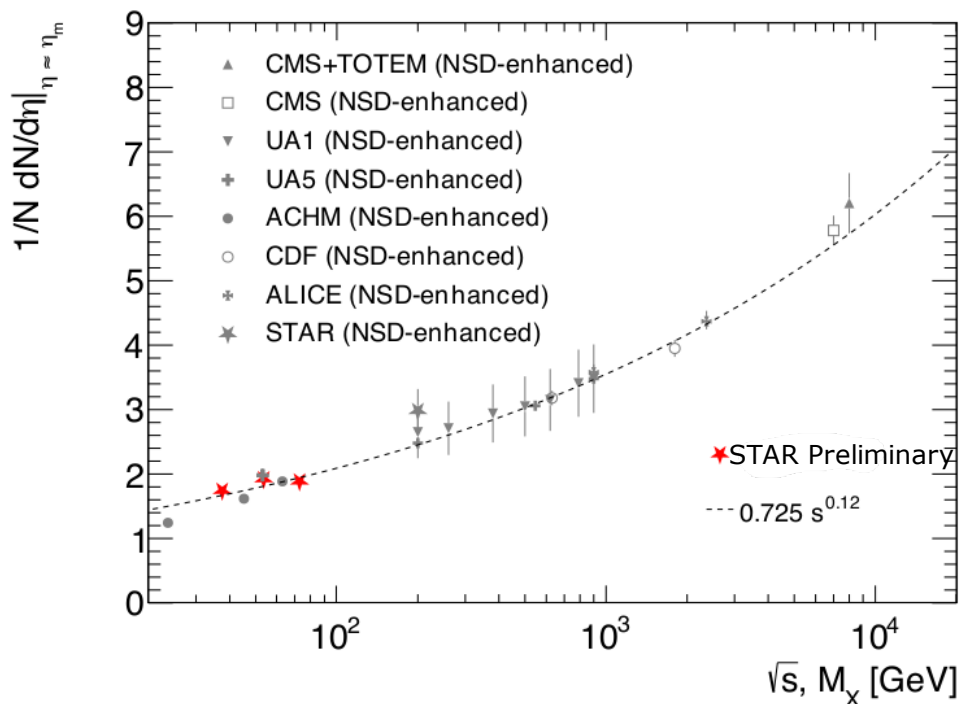


Figure 2: Primary charged particle densities at mid-rapidity as a function of \sqrt{s} and M_X for inelastic (non single diffractive (NSD) enhanced) and single diffractive measurements respectively. The dashed line represents power-law fit to the NSD-enhanced measurements [11].

64

65 The left panel in Fig. 3 shows the ratios of production yields of \bar{p}/p in three intervals of
 66 ξ as a function of p_T . In the last two ξ ranges, data are consistent with equal amounts of p
 67 and \bar{p} with no p_T dependence. However, in the first ξ range at $p_T < 0.7$ GeV/c, data show
 68 a significant deviation from unity indicating a large transfer of the baryon number from the
 69 forward to the central region. PYTHIA 8, EPOS-LHC SD' and EPOS-LHC (SD+SD') agree with
 70 data in the last two ξ ranges. In the first ξ range, PYTHIA 8 and EPOS-LHC SD' predict small
 71 deviation from unity by $\sim 5\%$, which is smaller than $\sim 15\%$ observed in data, while EPOS-
 72 LHC (SD+SD') predicts larger deviation by $\sim 25\%$. HERWIG SD predicts much larger baryon
 73 number transfer compared to data in all three ξ ranges. This observation is caused by the fact,

74 that HERWIG SD is effectively an extreme realization of the model in which there is almost
 75 always a baryon present at gap edge. Significant increase of \bar{p}/p ratio with increasing ξ is
 76 related to the fact that the gap edge is further away from the fiducial η region at larger ξ .

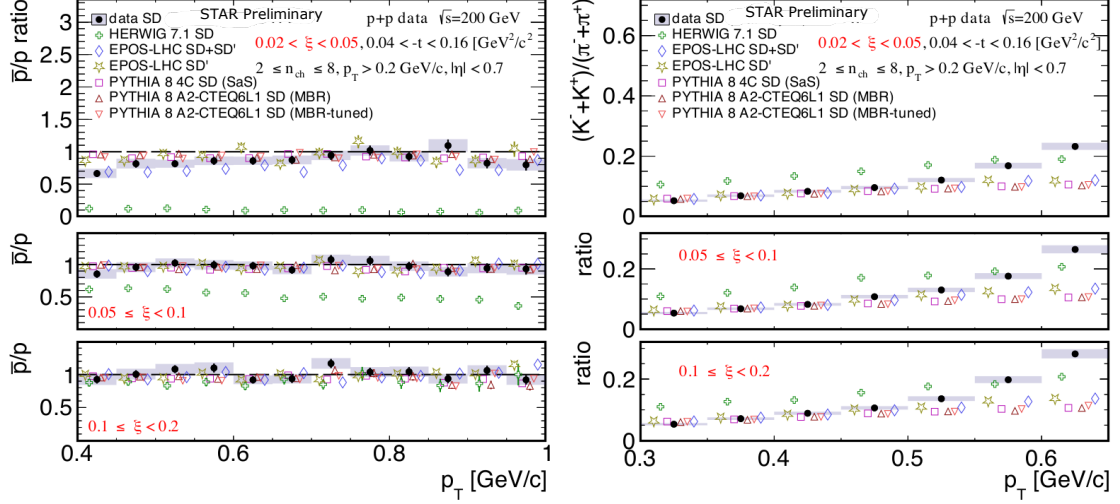


Figure 3: Ratio of production yields of \bar{p}/p as a function of p_T shown in three ranges of ξ : (top left) $0.02 < \xi < 0.05$, (middle left) $0.05 < \xi < 0.1$, (bottom left) $0.1 < \xi < 0.2$. Ratio of production yields of $(K^- + K^+)/(\pi^- + \pi^+)$ as a function of p_T shown in three ranges of ξ : (top right) $0.02 < \xi < 0.05$, (middle right) $0.05 < \xi < 0.1$, (bottom right) $0.1 < \xi < 0.2$. Data are shown as full dots with error bars representing the statistical uncertainties. Gray boxes represent statistical and systematic uncertainties added in quadrature. Predictions from MC models are shown as open symbols.

77 The right panel in Fig. 3 shows the ratios of production yields of $(K^+ + K^-)/(\pi^+ + \pi^-)$
 78 in three intervals of ξ as a function of p_T . The ratio increases from 0.05 at $p_T = 0.3$ GeV/c
 79 to 0.22 – 0.28 at $p_T = 0.65$ GeV/c. The slope of the p_T dependence significantly increases
 80 at $p_T = 0.5$ GeV/c in all three ξ intervals. The change of the p_T slope increases with ξ . All
 81 models predict very similar $(K^+ + K^-)/(\pi^+ + \pi^-)$ ratio except HERWIG, which predicts almost
 82 twice larger value independently from p_T . PYTHIA 8 and EPOS-LHC agree very well with data
 83 at $0.3 < p_T < 0.5$ GeV/c but do not expect a change of the slope of p_T dependence at $p_T > 0.5$
 84 GeV/c predicting rather almost twice smaller ratio at the highest p_T value.

85 3 Conclusion

86 Primary-charged-particle multiplicities are well described by PYTHIA 8 and EPOS-LHC SD/
 87 models. EPOS-LHC SD and HERWIG 7.1 do not describe the data. Similarity between the dis-
 88 sociation of a diffractively produced system of mass M_X and the hadronization of the system re-
 89 sulting from non-diffractive pp collisions at $\sqrt{s} \approx M_X$ was shown. \bar{p}/p production ratio shows
 90 a significant deviation from unity in the $0.02 < \xi < 0.05$ range indicating a non-negligible
 91 transfer of the baryon number from the forward to the central region. Equal amounts of pro-
 92 tons and antiprotons are observed in the $\xi > 0.05$ range. PYTHIA 8 and EPOS-LHC SD' agree
 93 with data for $\xi > 0.05$. For $0.02 < \xi < 0.05$ they predict small deviations from unity (0.93),
 94 however even larger effect is observed in the data (0.86 ± 0.02). This observation is consistent
 95 with increase of the baryon number transfer to the central rapidity region with decreasing

96 ξ expected from Ref. [12] where an extra baryon can appear close to the rapidity gap edge
97 (so called backward peak). At $p_T > 0.5$ GeV/c, the measured $(K^+ + K^-)/(\pi^+ + \pi^-)$ ratio is
98 significantly larger compared to inclusive inelastic measurements in pp or $\bar{p}p$ collisions. This
99 excess is not predicted by any model. It can be due to the smaller $s\bar{s}$ suppression in fragmenta-
100 tion process (factor 0.2 in PYTHIA 8) in diffractive system and p_T kicks during string(cluster)
101 breaking producing $s\bar{s}$ is larger compared to $u\bar{u}$ or $d\bar{d}$ production.

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105 References

- 106 [1] Hai-Yan Long et al., *Strange quark suppression and strange hadron production*
107 *in pp collisions at RHIC and LHC*, Physical Review C 84, 034905 (2011),
108 doi:[10.1103/PhysRevC.84.034905](https://doi.org/10.1103/PhysRevC.84.034905).
- 109 [2] K. Ackermann et al., *STAR detector overview*, Nucl. Instrum. Meth. A 499, 624 (2003),
110 doi:[10.1016/S0168-9002\(02\)01960-5](https://doi.org/10.1016/S0168-9002(02)01960-5).
- 111 [3] T. Sjöstrand et al., *A brief introduction to PYTHIA 8.1*, Comp. Phys. Commun. 178
112 (2008)788852, doi:[10.1016/j.cpc.2008.01.036](https://doi.org/10.1016/j.cpc.2008.01.036).
- 113 [4] G.A Schuler, T. Sjöstrand, *Hadronic diffractive cross-sections and the rise of the total cross-*
114 *section*, Phys. Rev. D 49 (1994) 2257, doi:[10.1103/PhysRevD.49.2257](https://doi.org/10.1103/PhysRevD.49.2257).
- 115 [5] J. Bellm, S. Gieseke, D. Grellscheid et al., *Herwig 7.1 Release Note*, arXiv:1705.06919805.
- 116 [6] S. Gieseke, F. Loshaj, P. Kirchgaesser, *Soft and diffractive scattering with the cluster model*
117 *in Herwig*, Eur. Phys. J. C 77 (2017) 156, doi:[10.1140/epjc/s10052-017-4727-7](https://doi.org/10.1140/epjc/s10052-017-4727-7).
- 118 [7] K. Werner, L. Karpenko, M. Bleicher, T. Pierog, *The physics of EPOS*, EPJ Web Conf.
119 52794(2013) 05001, doi:[10.1051/epjconf/20125205001](https://doi.org/10.1051/epjconf/20125205001).
- 120 [8] T. Pierog, Iu. Karpenko, J. M. Katzy, E. Yatsenko, K. Werner, *EPOS LHC: Test of collective*
121 *hadronization with data measured at the CERN Large Hadron Collider*, Phys. Rev.797C 92
122 (2015) 034906. doi:[10.1103/PhysRevC.92.034906](https://doi.org/10.1103/PhysRevC.92.034906).
- 123 [9] ATLAS Collaboration, *Further ATLAS tunes of PYTHIA 6 and Pythia 8*, ATL-PHYS-PUB-
124 2011-014.
- 125 [10] R. Ciesielski, K. Goulianos, *MBR Monte Carlo simulation in PYTHIA 8*,
126 arXiv:1205.1446801.
- 127 [11] CMS and TOTEM Collaborations, *Measurement of pseudorapidity distributions of charged*
128 *particles in proton-proton collisions at $\sqrt{s} = 8$ TeV by the CMS and TOTEM experiments*,
129 Eur. Phys. J. C 74 (2014) 3053, doi:[10.1140/epjc/s10052-014-3053-6](https://doi.org/10.1140/epjc/s10052-014-3053-6).
- 130 [12] F.W. Bopp, *Central baryons in dual models and the possibility of a backward peak in diffrac-*
131 *tion*, arXiv:hep-ph/0002190.